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Published in:
Proceedings of SB 13 Dubai Conference

Publication date:
2013

Document Version
Publisher's PDF, also known as Version of record

Energy Use and Indoor Climate in Two Schools Before and After Deep Energy Renovation

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ABSTRACT

Denmark is participating in IEA ECBCS Annex 61 "Development and demonstration of concepts for deep energy retrofit in government/public buildings". The purpose of the Annex is to improve the decision-making process to achieve deep energy retrofits of government/public buildings, starting with the determination of working bundles of technologies and corresponding business models using combined public and private funding.

Denmark will contribute to the project with 7 buildings in total, i.e. 2 schools and 5 kindergartens/institutions, which will undergo deep energy renovation over the next few years. The 7 buildings are being energy renovated and monitored with support from the EU-CONCERTO initiative as part of the project "Cost-effective Low-energy Advanced Sustainable So1utions – Class1".

The buildings are very different and therefore the energy renovations to take place will also vary from building to building. The gross list of energy saving measures that will be implemented includes: Improved insulation of roof and external walls, new low-energy windows and shading systems, new or renewed ventilation systems with heat recovery, low energy lighting, water saving measures, improved insulation of piping and improved control (Building Energy Management Systems – BEMS).

This paper presents preliminary results of analysis and monitoring of energy use and indoor climate in the two public schools before and after deep energy renovation

KEYWORDS: Energy, Renovation, Public Buildings, Indoor Climate, Analysis, Monitoring

1. INTRODUCTION

Improving of the energy efficiency of buildings represents a key target area in European countries, since 40% of the total energy consumption in the EU is related to the building sector (European Commission, 2010). This implies, among other things, increasing the energy standard of existing buildings in order to reduce heat loss through building envelopes and implementing a greater share of renewable energy in buildings.

The scope of the Annex 61 project is to improve the decision-making process associated with achieving deep energy renovation of government/public buildings (office/administrative buildings, dormitories/bar-racks, education buildings, etc.), starting with the determination of working bundles of technologies and corresponding business models using combined public and private funding. This decision-making process must improve to overcome existing barriers in the execution of complex projects co-funded by government, public entities, ESCOs, and other market partners. Barriers include the exclusion of individual ECMs (Energy Conservation Measures) with long payback times, and the challenges of combining energy-related measures with non-energy-related measures (e.g., building sustainment, repurposing, and improvement in quality of life). The objectives of Annex 61 are to:

- Provide a framework and selected tools and guidelines to significantly reduce energy use (by more than 50%) and to improve indoor environment quality in government and public buildings and building communities undergoing renovation
- Gather and, in some cases research, develop, and demonstrate innovative and highly effective bundled packages of ECMs for selected building types and climatic conditions
- Develop and demonstrate innovative, highly resource-efficient business models for retrofitting/refurbishing buildings and community systems using appropriate combinations of public and private funding such as ESPC (Energy Savings Performance Contracts) and other concepts to be developed together with the building owners
- Support decision makers in evaluating the efficiency, risks, financial attractiveness, and contractual and tendering options conforming to existing national legal frameworks
- Engage end users, mainly building owners and other market partners, in the proceedings and work of the Annex Subtasks.

The IEA Annex 61 working phase starts 1 July 2013 and ends at September 2016.

Egedal Municipality is participating in the EU Class1 project with energy renovation of 7 municipal buildings. The Class1 project is part of the so-called CONCERTO initiative – Energy solutions for smart cities and communities http://concerto.eu/concerto/. In a CONCERTO project energy conservation within buildings and renewable energy supply goes hand-in-hand in a chosen community. Egedal Municipality is participating with Stenløse town, where a number of new dwellings have been constructed and renovation of public – municipal buildings are about to begin. The renewable energy supply will be in the form of large-scale PV-installations on the municipal buildings.

The municipal buildings that undergo energy renovation will be the Danish contribution to IEA ECBCS Annex 61 – Development and Demonstration of Financial and Technical Concepts for Deep Energy Retrofits of Government/Public Buildings and Building Clusters.

2. RENOVATION OF PUBLIC BUILDINGS IN EGEDAL

2.1 The energy renovation projects – a short presentation

The energy renovations to be carried out by Egedal Municipality encompass 7 public buildings – 2 schools: Bækkegårdsskolen and Stengårdsskolen and 5 kindergarten/institutions. The total area to be renovated is 20,443 m^2. The two schools are approximately 8,500 and 9000 m^2 respectively and the remaining buildings between 500 and 1,000 m^2. The photos in figure 1, 2 and 3 show the two schools.

Bækkegårdsskolen is from 2002 – 2004, so it is a relatively new school. The roof and external walls are light constructions insulated with 250 mm mineral wool.

Figure 1. Bækkegårdsskolen before renovation

Stengårdsskolen consists of 2 buildings erected in the years 1970-1978. The external walls are concrete sandwich type walls with an insulation thickness of 75 mm. The main – most costly – energy renovation measure is external insulation with new cover plates of all the external walls, see figure 3.


Figure 2. Stengårdsskolen before renovation


Figure 3. Stengårdsskolen – schematic drawing of the school after renovation

2.2 Installation of PV-systems on the public buildings

The Municipality of Egedal has installed 9 PV-systems comprising a total of 916.3 kWp with a total guaranteed annual electricity production of 885,113 kWh. Figure 4 shows one of the facilities.


Figure 4. PV installation at Stengårdsskolen: 220 kWp – yearly production 173 MWh

2.3 The energy renovation to take place

The energy renovation of the 7 public buildings has been split in two major packages: Package 1 is the façade renovation of Stengårdsskolen which was designed to give a complete new impression of the school from the outside. An architectural company has designed the new façade and is responsible for the implementation. Package 2 was all other energy renovation works on the 7 buildings. This package is handled by a local engineering company who has contracted each part out to different sub-contractors depending on the nature of the renovation works. The energy renovation technologies in play are:

- Installation of Building Energy Management Systems for better control of heating and ventilation systems incl. circulation of domestic hot water
- CO_2 – control of ventilation systems
- Insulation of pipes, ducts and heat exchangers
- Insulation of roofs
- Insulation of floors above basements
- Insulation of basement floor towards the ground
- Insulation of walls towards non-insulated rooms
- New well-insulated light façade-system
- Change of piping incl. layout – and dismantling of electrical heating of piping (el-tracing)
- Change from electrical to Hydronic preheating of ventilation air
- Closing down old exhaust ventilation systems
- Installation of new ventilation systems with heat recovery
- Replacing windows and doors
- New electrical lighting system
- Mounting of solar collectors
- Closing of old roof lights
- Installation of new low-energy circulation pumps on the hydronic heating system.

The engineering company have carried out optimization calculations for all buildings and hereby identified which technologies are to be implemented in which buildings. In this paper we use Stengårdsskolen as an example and the technologies implemented here are:

- New facades on external walls including 250 mm of additional insulation.
- Additional roof insulation
- New mechanical ventilation system with heat recovery
- New electrical lighting system with advanced control
- Improved insulation of technical installations – pipes and ducts
- Improved electrical lighting system in the basement
- New circulation pumps on the Hydronic heating system
- PV system on the roof

3. ENERGY CALCULATIONS AND MEASUREMENTS

3.1 Calculations

The overall CONCERTO requirement is that the energy renovation of the buildings shall result in a final energy consumption that does not exceed what is required for new buildings according to the Building Regulation (BR) in force. In this case the Class1 project was initiated in autumn 2007 and the BR in force was BR08.

The buildings are of different age and therefore their energy consumption varies in the range from 145 – 284 kWh/m²/year (calculated according to the Danish "Energy-frame" calculation procedure, where electricity consumption is multiplied by a factor 2.5). The goal according to BR08 is an energy frame of 95 kWh/m²/year, corresponding to reductions of 34 % - 67 % in energy use.

The two schools have a pre-renovation primary energy consumption of about 145 kWh/m²a. As the monitoring has not yet been conducted over a winter period this paper can only present the calculated results. The first actual measured data will be presented at the conference in Dubai. Calculated results for Stengårdsskolen are presented in figure 5 and table 1.

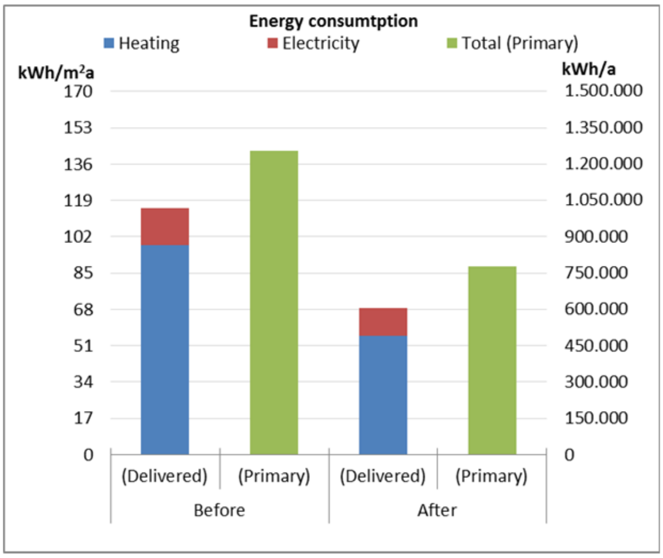

Figure 5. Delivered and primary energy consumption before and after the energy renovation

It appears that the primary energy consumption at Stengårdsskolen is reduced by 34% by implementing the energy renovation measures. Taking into consideration also the energy production by the PV system on the school the primary energy is reduced an additional 49 kWh/m²a down to 39 kWh/m²a, which corresponds to what is today referred to as "low-energy class 2015" requirements in the present Danish Building Regulations. "Low-energy class 2015" is expected to become the requirement for new buildings from 2015 and onwards.

The total CO_2 reduction is 394 tons/a for the energy saving measures and 87 tons/a for the PV system, i.e. a total CO_2-reduction of 481 tons/a.

Table 1. Energy consumption before and after the energy renovation of Stengårdsskolen

Annual energy consumption	Heating [kWh/m^{2}a]	Electricity [kWh/m^{2}a]	Total (Primary) [kWh/m^{2}a]	Total (Primary) [kWh/a]
Before energy renovation	97.7	17.7	142.0	1,254,412
After energy renovation	55.5	13.0	88.0	777,656
Energy saving	42.2	4.7	54.0	476,756

3.2 Measurements

Systems for continuous energy monitoring have been installed on all the 7 Class1 public buildings. The system is internet based and all data are available online. In a similar way online monitoring of the electricity production of all PV-systems has been installed.

The data from these systems will first be analyzed as part of the Class1 project and later in the context of the IEA Annex 61.

4. INDOOR CLIMATE MEASUREMENTS

Investigations have been performed in classrooms in the schools before renovation – two classrooms at Stengårdsskolen and two classrooms at Bækkegårdsskolen.

The investigations included continuous registration of indoor air temperature, relative humidity and CO_2-concentration. Registrations were made using programmable data loggers with registration every 5 minutes. Furthermore, the ventilation in the classrooms was measured using passive tracer gas technique, the so-called PFT technique. Measurements with the PFT technique are performed over a period, and the result of a measurement is the average ventilation conditions during the measurement period. Finally, a survey among the students was conducted.

The investigations were conducted from February 1st to February 20th 2013. The period includes a normal working week (from February 4th to February 8th), where the classrooms were in normal use for lessons, and a holiday week (from February 11th to February 15th), where the rooms were unoccupied and not in use. The compilation of results below reflects the two periods. The ventilation measurements however, include the neighboring weekends and the measurement in one of the classrooms at Bækkegårdsskolen covers the full period.

Table 2. Results of ventilation measurements using passive tracer gas technique

	School	Measurement period		ACH [h^{-1}]
1a	Stengårdsskolen, Room 58 (7A)	Feb. 1st to Feb. 8th	Normal week	0.29 ± 15 %
1b	Stengårdsskolen, Room 58 (7A)	Feb. 8th to Feb. 20th	Holiday week	0.29 ± 15 %
2a	Stengårdsskolen, Room 40 (6A)	Feb. 1st to Feb. 8th	Normal week	0.86 ± 15 %
2b	Stengårdsskolen, Room 40 (6A)	Feb. 8th to Feb. 20th	Holiday week	0.81 ± 15 %
3a	Bækkegårdsskolen, Room G44 (7B)	Feb. 1st to Feb. 8th	Normal week	0.33 ± 15 %
3b	Bækkegårdsskolen, Room G44 (7B)	Feb. 8th to Feb. 20th	Holiday week	0.38 ± 15 %
4	Bækkegårdsskolen, Room G28 (6A)	Feb. 1st to Feb. 20th	Normal week + Holiday week	0.59 ± 15 %

It is possible for each of the classrooms at Stengårdsskolen to identify periods where there is a uniform, continuous decay in the CO_2 concentration. Figure 7 below shows an example from classroom 58 (7A). Assuming the classroom is unoccupied during periods with a uniform, continuous decay in the CO_2-concentration, the air change rate during these periods can be determined on the basis of decay curves.

The calculation is based on rewriting the equilibrium equation:

$$n = 2.3 \cdot \frac{\log\left(\frac{c_1 - c_i}{c_2 - c_i}\right)}{\tau_2 - \tau_1}$$

Where n is the air change rate [h^{-1}], c_1 and c_2 are concentrations at time τ_1 [h] and τ_2 [h], respectively and c_i is the background concentration.

The calculation takes into account the background concentration of CO_2. Through comparing this result with the result of the ventilation measurement using the passive tracer gas technique, which determines the average air change rate during the entire period, the air change rate during periods of use – i.e. teaching time – can be estimated.

Figure 6 shows the measured CO_2-concentration in the classroom during a part of the measurement period. The orange lines indicate a period when the room is assumed unoccupied. The air change rate during that particular period is calculated to approx. 0.18 h^{-1}.

The result of the PFT-measurement, which includes a period of 7 days (169 hours), is measured to 0.29 h^{-1}.

Based on the entire measurement period, it is estimated that the classroom is effectively used for approx. 24 hours corresponding to about 14 % of the total measurement period of 169 hours. The average air change rate during teaching time can thus be estimated to approx. 1.0 h^{-1}.

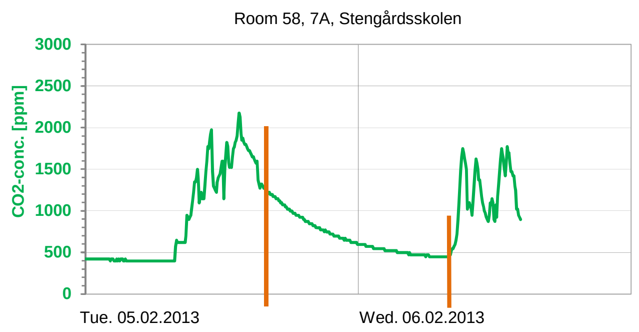

Figure 6. CO_2-concentration. Orange lines indicate a period where the room is considered unoccupied

Table 3. Compilation of all registrations in Room 58 (7A) using programmable data loggers

		Min.	Avg.	Max.	Std. Dev.	%
Normal week (Mon. – Fri.)	T [°C]	19.4	23.8	26.5	1.6	6.5
	RH [%]	20.5	27.8	37.1	3.5	12.6
	CO_2 [ppm]	396	811	3034	453	55.8
Weekend (Sat./Sun.)	T [°C]	23.0	23.4	23.6	0.1	0.6
	RH [%]	18.0	20.1	23.9	1.6	8.1
	CO_2 [ppm]	397	433	496	16	3.7
Holiday week (Mon. – Fri.)	T [°C]	22.7	23.0	23.7	0.2	0.8
	RH [%]	16.8	18.5	21.0	0.9	5.0
	CO_2 [ppm]	422	432	472	15	3.4

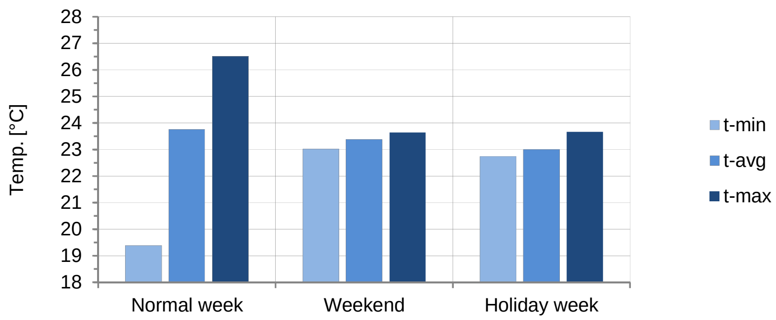

Figure 7. Room temperature in Room 58 (7A) – minimum, average and maximum in three periods

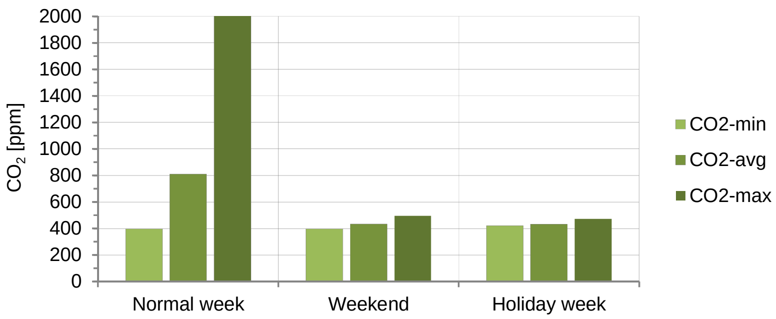

Figure 8. CO_2-concentration in Room 58 (7A) – minimum, average and maximum in three periods

The investigated classrooms at Bækkegårdsskolen are ventilated by decentralized mechanical ventilation. The systems are controlled by sensors in the rooms, so that the mechanical ventilation is active and with a high ventilation rate when there are people present in the room, whereas the ventilation is reduced when the classrooms are unoccupied. However, there does not appear, in the same way as seen at Stengårdsskolen, a continuous decay in the CO_2-concentration during periods of non-use. The reason may be that the ventilation systems, in addition to being controlled by occupants' presence, are controlled by other means e.g. timers, so that the ventilation rate is not constant when the rooms are unoccupied, though this has not been verified. It is therefore not possible to calculate air change rates split into periods of use and non-use.

All types of measurements performed before renovating the two schools will be repeated after the renovations.

5. CONCLUSIONS

Denmark is participating in the IEA ECBCS Annex 61 and will contribute with 7 public buildings that have undergone deep energy renovation. This paper has presented measurements and calculations of indoor climate and energy consumption from 2 public schools along with expected energy consumption after renovation.

Indoor climate measurements show that the average air change rate in the classrooms is rather low – 0,3 - 0,9 ACH during a normal week. Consequently, CO2-concentrations are somewhat high, in particular during class hours where the CO2-concentration generally peaks at about 2000 ppm in Room 58 (7A) and about 1500 ppm in the other classrooms investigated. The indoor temperature is high in three of the four classrooms investigated – about 25 °C during class hours as well as during weekends and holidays. In Room 40 (6A) at Stengårdsskolen the average temperature is 3 - 4 °C lower. Significant improvements after renovations are expected.

Measurements and calculations of energy consumption for Stengårdsskolen show an expected reduction in primary energy consumption from 143 kWh/m^{2}a to 88 kWh/m^{2}a from energy efficiency measures alone and a further 49 kWh/m^{2}a reduction resulting from the electricity production in the PV system. The primary energy use after renovation is expected to be 39 kWh/m^{2}a, corresponding to expected requirements for new buildings in 2015 and a total reduction of CO_2-emissions of 481 tons/a.

Further measurements of indoor climate and measurements of energy consumption in the renovated buildings will be presented at the conference in Dubai, December 2013.

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